A Rb/Sr whole-rock isochron date from the lowermost gneiss complex of the Gaular area, west Norway and its regional implications

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The Precambrian rocks within the Gaular area can be tectonically divided into two major rock units; a lower complex (Jostedal Complex), which largely consists of migmatites and gneiss-granites, and an overlying largely metasupracrustal sequence. The latter unit, which may be subdivided into the Holsen Gneiss (mainly quartz-rich paragneisses) and the Vevring Complex (mainly amphibolites, paragneisses, and eclogitic rocks), has been interpreted as a thurst sheet, the Sunnfjord nappe.

The Jostedal Complex yields a metamorphic Rb/Sr whole-rock isochron date of 1625 ± 75 m.y. An initial $^{87}Rb/^{86}Sr$ ratio of 0.701 ± 0.002 excludes an extended crustal history prior to the major metamorphism. Two biotite/whole-rock ages of 392 ± 15 m.y. and 396 ± 15 m.y. provide evidence for a Caledonian influence in the area.

It is assumed that the emplacement of the Sunnfjord nappe took place late in the Sveconorwegian (Grenvillian) orogeny.

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The age and status of the Gneiss Region of west Norway has been a matter of debate for many years. Irgens & Hiortdahl (1864), Reusch (1881), and Kolderup (1928) regarded the gneisses as forming a Precambrian basement to the overlying Lower Palaeozoic sequence. Holtedahl (1936, 1938, 1944) re-interpreted the gneisses as having been formed by Caledonian high-grade metamorphism, migmatization, and granitization of both Lower Palaeozoic metasupracrustals and Precambrian rocks. This interpretation was supported by, amongst others, Kolderup (1952) and Strand (1960).

Bryhni (1966), however, recognized the existence of a reworked pre-Eocambrian basement complex of relatively homogeneous gneisses – the Jostedal Complex – overlain by a heterogenous complex – the Fjordane Complex – comprising Cambro-Silurian as well as older rocks corresponding to the Jotun nappe. Also Skjerlie (1969) and Strand (1969) divided the gneisses in Askvoll-Gaular and Grotli areas respectively into a Precambrian basement (identical with Bryhni's Jostedal Complex) and an overlying sequence of postulated Late Precambrian to Ordovician age.

It is quite obvious that a satisfactory understanding of the chronology and the metamorphic development of the Gneiss Region can only be obtained by applying a number of modern radiometric dating techniques in combination with known geological relationships. Several important contributions have already been made towards this end (Broch 1964, McDougall & Green 1964, Brueckner et al. 1968, Priem 1967, Priem 1968, Priem et al. 1970, Bryhni et al. 1971, Brueckner 1972, Pidgeon & Råheim 1972, and Sturt et al. 1975).

To date, however, the only Rb/Sr whole-rock and mineral isochrons obtained from rocks in the Gaular area are those from the Holsen Gneiss and associated pegmatites on the north shore of Holsavatn (Brueckner 1972). In this paper we add one new Rb/Sr whole-rock isochron age and two Rb/Sr biotite/whole-rock ages for the lowermost gneisses in the Gaular area.

Geological setting

Skjerlie (1969) described the pre-Devonian rocks in the Gaular area as Precambrian basal gneisses overlain by a metasupracrustal sequence of postulated Late Precambrian to Ordovician age. In the latter, the Holsen Group was identified as the oldest unit, and this is succeeded by the Askvoll, Stavenes and Lower Herland Groups.

Furnes et al. (1976), however, divided the metasupracrustal rocks into two principal units based on a pronounced change in metamorphic grade and lithology across major faults between the lower and upper parts of the former Askvoll Group, suggesting quite different age relations. The metamorphic grade of the upper unit does not exceed greenschist facies. This unit was assigned to the Askvoll Group and assumed to be of Lower Palaeozoic age. The rocks of the lower unit, however, preserve almandine-amphibolite facies assemblages, and frequently contain inclusions of eclogitic rocks. This unit comprises the former Holsen Group and the higher grade metamorphic rocks of the former Askvoll Group. In the present account they are retermed the Holsen Gneiss and the Vevring Complex, respectively. Radiometric age-dates in the Holsen area (Brueckner 1972), and in the Nordfjord district farther towards the northwest (Bryhni et al. 1971), have clearly proven a Precambrian age for both the Holsen Gneiss and the Vevring Complex.

The basal gneisses of Skjerlie (1969) undoubtedly correspond to the Jostedal Complex as defined by Bryhni (1966), and the present authors have, therefore, found it adequate to use this term for the lowermost gneisses also in the Gaular area.

As pointed out by Bryhni (1966), the Jostedal Complex forms a large culmination and represents the deepest exposed level in the central Caledonides. The complex consists of migmatites, granitic gneisses, and augen gneisses. Palingenetic granites, in places with originally gneissic structures, also occur. The whole complex is frequently cut by pegmatites.

The rather monotonous Jostedal Complex is overlain by the Holsen Gneiss which consists mainly of quartz-rich paragneisses, quartz schists, augen gneisses, and amphibolites. Pegmatites occur locally, and especially within the Holsen district.

A gradual transition exists from the Holsen Gneiss upwards into the Vevring Complex where the dominating rock types are amphibolites, eclogitic rocks, paragneisses, quartz schists, granitic rocks, and meta-anorthosites. Ultrabasic and basic inclusions also occur.

The Holsen Gneiss is separated from the Jostedal Complex by a distinct thrust-zone and the metasupracrustal sequence (Holsen Gneiss and Vevring Complex) has been interpreted as a thrust sheet, the Sunnfjord nappe.

The Gaular area has undergone at least three phases of folding of presumed Caledonian age (Skjerlie 1969). Fold axes strike ESE-WNW (oldest), NE-SW, and E-W (youngest). It appears (Fig. 1) that the Vevring Complex occurs in separate eastern and western areas. Between these two the Holsen Gneiss forms the core of a recumbent anticline with an axial plane dipping gently south-east. The formation of this anticlinal structure was produced by the second phase of folding (NE-SW).

Sampling

A number of samples were collected in fresh roadcuts. Particular emphasis was laid on the Jostedal Complex and samples were taken from gneissic rocks as well as aplites and palingenetic granites. Samples were also collected from granitic rocks which intrude the Vevring Complex. Unfortunately, however, both the aplites and the granites associated with the Jostedal Complex as well as the granites intruding the Vevring Complex have very low and uniform Rb/Sr ratios.

A whole-rock Rb/Sr isochron date could, however, be obtained on gneissic rocks from the area WNW of Hæstadfjorden (Fig. 1).

Analytical techniques

The samples were analysed using standard isotope dilution techniques on an Atlas CH4 mass spectrometer equipped with a digital output. ^{84}Sr spike was used for all strontium analyses and the data normalized to a $^{86}Sr/^{88}Sr$ ratio of 0.1194. ^{87}Rb spike was used for rubidium analyses. The experimental uncertainties are estimated at 1.5% and 0.1% for the $^{87}Rb/^{86}Sr$ and $^{87}Sr/^{86}Sr$ ratios respectively. The isochron ages were computed using York's model II program (York 1969) with $\lambda^{87}Rb = 1.39 \times 10^{-11} yr^{-}{}_{1}$ and the errors given at the two sigma level.

Analytical results

In all, ten whole-rock samples from gneissic rocks from the Jostedal Complex were analysed,

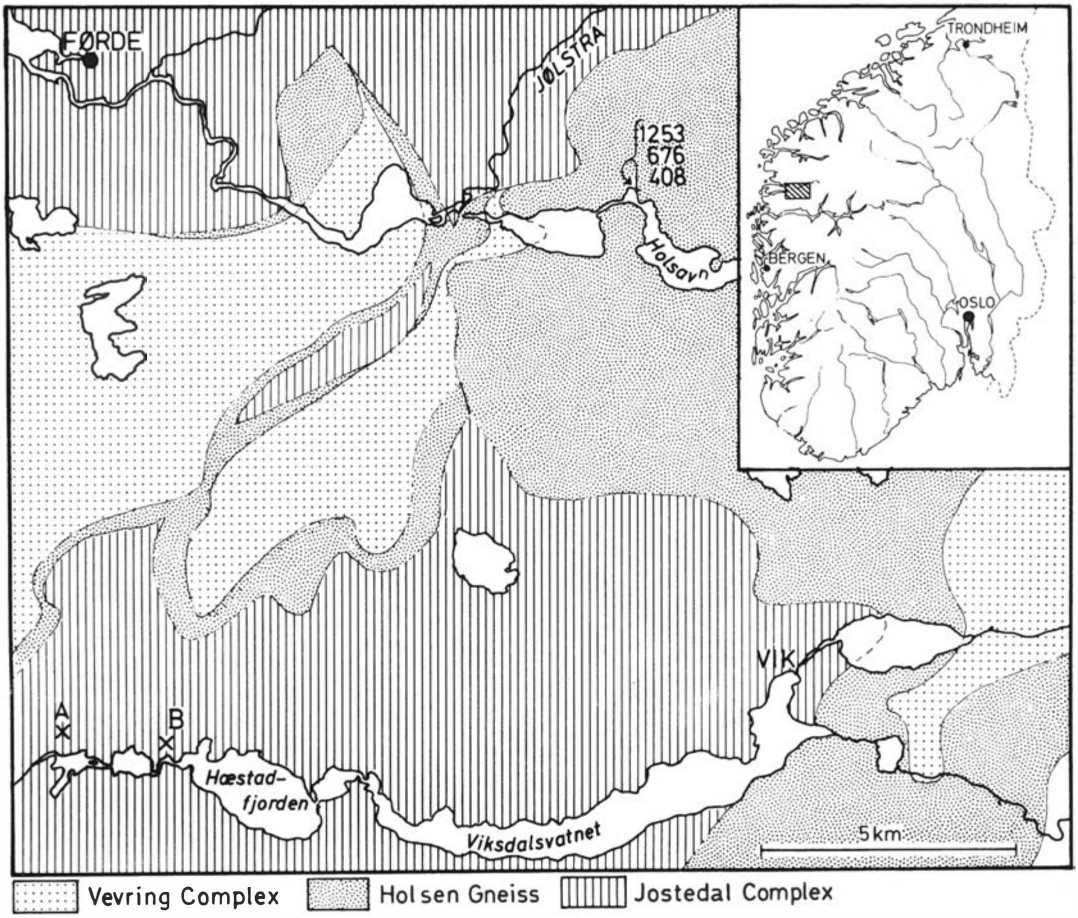

Fig. 1. Simplified geological map of the Gaular area showing sample localities and published whole-rock and mineral ages (in million of years). A and B: sample localities.

Table 1. Rb-Sr data of the investigated samples plotted in the $^{87}Sr/^{86}Sr$ versus $^{87}Rb/^{86}Sr$ diagram (Fig. 2). WR, whole-rock; Bi, Biotite concentrate.

Sample No.	Rb (ppm)	Sr (ppm)	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
1005 WR	78.10	292.9	0.77	0.7206
1006 WR	127.7	125.9	2.94	0.7656
1009 WR	155.3	255.5	1.76	0.7375
1010 WR	113.2	142.9	2.30	0.7539
1011 WR	101.2	119.5	2.46	0.7601
1014 WR	73.14	94.3	2.25	0.7491
1017 WR	57.92	124.8	1.34	0.7297
1018 WR	71.80	98.44	2.11	0.7495
1020 WR	64.54	108.8	1.72	0.7455
1021 WR	56.89	50.42	3.28	0.7732
1005 Bi	377.1	7.21	164.5	1.6163
1006 Bi	556.3	5.71	333.4	2.5916

five (1005, 1006, 1009, 1010, 1011) of which were collected at locality B (Fig. 1), the other five (1014, 1017, 1018, 1020, 1021) at locality A. The Rb/Sr whole-rock isotopic data are reported in Table 1, together with isotopic analyses of biotite from two of the samples (1005, 1006). The analytical data are plotted on an isochron diagram (Fig. 2).

The ten point isochron obtained indicates a metamorphic age of 1625 ± 75 m.y. The low initial $^{87}Sr/^{86}Sr$ ratio ($R_i = 0.701 \pm 0.002$) suggest that the rocks could not have had a long crustal history prior to the major metamorphism.

The Rb/Sr biotite/whole-rock isochrons obtained from two of the samples give ages of 392 and 396 m.y. with initial $^{87}Sr/^{86}Sr$ ratios of 0.7164 and 0.7494 respectively. These results are consistent with a number of Caledonian mineral

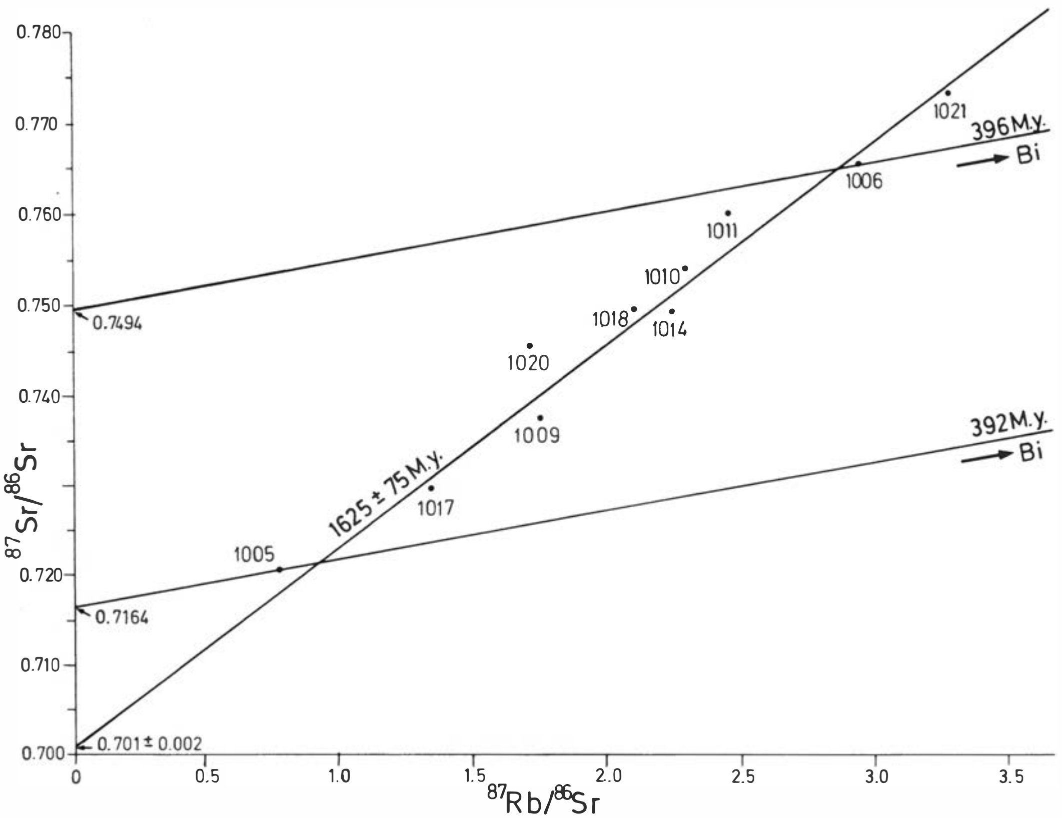

Fig. 2. Rb-Sr isochron plot of analytical results from whole-rock and biotite concentrates from gneissic rocks, the Jostedal Complex.

ages within the range 372–427 m.y. which have been recorded from other parts of the Gneiss Region (Broch 1964, McDougall & Green 1964, Brueckner et al. 1968, Strand 1969, Priem et al. 1970, Bryhni et al. 1971, Brueckner 1972, Pidgeon & Råheim 1972, Sturt et al. 1975).

Conclusion and discussion

The age of the major metamorphism of the Jostedal Complex in the Gaular area, defined by a ten point Rb/Sr whole-rock isochron is 1625 ± 75 m.y. This isochron age fits into the age range of the Svecofennian orogen (Kratz et al. 1968) and also corresponds to the second Laxfordian metamorphism (LM2) of the Scottish Lewisian (Moorbath & Park 1971). The low initial $^{87}Sr/^{86}Sr$ ratio ($R_i = 0.701 \pm 0.002$) suggests that these gneissic rocks from the Jostedal Complex did not have a long crustal history prior to the major metamorphism.

Pidgeon & Råheim (1972) obtained Rb/Sr whole-rock isochron ages of 1708 ± 60 m.y. for gneissic rocks belonging to the Kristiansund (Raudsand) and Frei Groups in the Kristiansund area. These authors interpreted the results as reflecting the age of the amphibolite facies metamorphism; the initial $^{87}Sr/^{86}Sr$ ratio of 0.7038 ± 0.0018 was taken as an indication that the rocks of the Kristiansund Group did not have a long crustal history prior to 1700 m.y. Neither was any isotopic event detected between 1700 m.y. and 400 m.y.

Skjerlie (1969) correlated the Frei and Raudsand (Kristiansund) Groups with the Jostedal Complex. This correlation was confirmed from the Tafjord-Grotli area where, according to Hernes (1970), the contact between the Jostedal Complex and the metasupracrustal sequence coincides with the contact between the Raudsand (Kristiansund) Group and the overlying Tingvoll Group of the Møre district.

Brueckner (1972) obtained a Rb/Sr whole-rock isochron age of 1253 ± 100 m.y. and an initial $^{87}Sr/^{86}Sr$ ratio of 0.7088 ± 0.0047 on gneissic rocks from the north shore of Holsavatn, and he drew the conclusion that this age represented the Sveconorwegian orogenic cycle. Brueckner believed that the analysed gneisses belonged to the Jostedal Complex. According to Skjerlie (1969), however, these are part of the Holsen Gneiss (Fig. 1).

The possibility that the Holsen Gneiss is considerably older than the Rb/Sr whole-rock isochron age obtained by Brueckner (1972) must not, however, be ruled out. Considering the initial $^{87}Sr/^{86}Sr$ ratio ($R_i = 0.7088 \pm 0.0047$) of the analysed samples, the age of 1253 ± 100 m.y. could reflect a metamorphic overprint. Such an overprint has been reported from the Vevring Complex farther towards the northwest, where McDougall & Green (1964) obtained K-Ar ages on eclogites in the 1740–1850 m.y. and the 950–1170 m.y. range. These results give a minimum age of about 1800 m.y. for the ecologites and a metamorphic overprint due to the Sveconorwegian orogeny. Bryhni et al. (1971) suggest an important overprint in the Fjordane Complex (Vevring Complex of Skjerlie & Pringle) at around 1022 ± 18 m.y. ago on the basis of $^{40}Ar/^{39}Ar$ age-spectrum analysis of pyroxene concentrate.

Rb/Sr whole-rock analyses of schists and gneisses from Almklovdalen, which undoubtedly correspond with the Vevring Complex in the Gaular area, yield an age around 1150 m.y. and an initial $^{87}Sr/^{86}Sr$ ratio of 0.710 ± 0.01 (Brueckner 1972). Brueckner suggested that there is some evidence that this apparent age is not a simple in situ crystallization age or homogenization age, and that the rocks may have undergone some isotopic redistribution at some stage in their history. In the present authors' opinion, the relatively high initial $^{87}Sr/^{86}Sr$ ratio suggests that the obtained age of 1150 m.y. represents a metamorphic overprint.

On the basis of the different analytical results from different parts of the Precambrian metasupracrustal rocks (Holsen Gneiss and Vevring Complex), it seems reasonable to conclude that these rocks have been affected by a penetrative reworking during the Sveconorwegian (Grenvillian) orogeny.

Even if some authors argue that country rock eclogites in western Norway are tectonically emplaced lower crustal or upper mantle environments (O'Hara & Mercy 1963, Lappin 1966) most geologists which have studied these rocks interpret them as in situ crustal metamorphic rocks (Gjelsvik 1952, Hernes 1954, Kolderup 1960, Schmidt 1960, Bryhni et al. 1969, Skjerlie 1969, Bryhni et al. 1970). The results of McDougall & Green (1964) could, therefore, suggest a minimum age of about 1800 m.y. for the eclogite bearing metasupracrustals.

The Rb/Sr whole-rock isochron obtained (Fig. 2) is not ideal. The dispersion of the analytical results reflects a later metamorphic event of probable Sveconorwegian age during which both the Rb/Sr and $^{87}Sr/^{86}Sr$ ratios were slightly disturbed. The Jostedal Complex seems not, however, to have been so strongly influenced by the Sveconorwegian orogeny as the overlying Holsen Gneiss and Vevring Complex. This circumstance could be explained by assuming that the Precambrian metasupracrustal rocks underwent Sveconorwegian reworking somewhere outside the Gaular area, and were later brought into their present position by thrust tectonics. The emplacement of the tectonic unit most probably took place late in the Sveconorwegian orogeny since the Vevring Complex already constituted considerable portions of the continental crust by the opening stage of the Iapetus ocean in latest Precambrian–earliest Cambrian time (Furnes et al. 1976).

It is difficult to forward proof of tectonic emplacement in the Precambrian due to the fact that younger Caledonian events have led to disturbances and small-scale thrustings along the supposed older thrust-plane.

Brueckner et al. (1968) obtained a Rb/Sr whole-rock isochron age of 1060 ± 160 m.y. ($1.39 \times 10^{-11} y^{-1}$ ^{87}Rb decay constant) for gneisses from the Tafjord area which were believed to belong to the Jostedal Complex. The sample localities were, however, situated very close to the supposed contact between the Jostedal Complex and the overlying metasupracrustal sequence. The analysed rocks are monotonous strongly banded gneisses containing no obvious metasedimentary or metavolcanic features and have a tectonic fabric parallel to that in the overlying metasupracrustal rocks. In the present authors' view these rocks probably correspond to mylonitic rocks in the Gaular area which occur in a broad zone along the contact between the Jostedal Complex and the Holsen Gneiss. The age obtained by Brueckner et al. (1968), therefore, probably represents an overprint caused by movements associated with the mylonitization.

Pegmatitic rocks are usually rather scarce within the Precambrian metasupracrustals. At some localities, however, the Holsen Gneiss contains abundant pegmatite bodies which as a rule show deformation phenomena. Four samples from a single pegmatite body from the north shore of Holsavatn defined a whole-rock isochron age of 676 ± 110 m.y. and an unusually high initial $^{87}Sr/^{86}Sr$ ratio of 0.7659 ± 0.0055 (Brueckner 1972). If this apparent age is accepted as meaningful, according to Brueckner it would suggest that the host rocks suffered a period of pegmatite emplacement late in the Sveconorwegian cycle or early in the Caledonian cycle. Samples from three separate pegmatite bodies were not co-linear and did not define a meaningful isochron age. This could, according to Brueckner, be explained either by local anatexis of the immediately adjacent country rocks or by intrusion from a common parental magma. In the latter case the pegmatites could have aquired different initial $^{87}Sr/^{86}Sr$ ratios through differential contamination during intrusion. In either case, the host rocks would have been partially open to the migration of Rb and Sr. In the present authors' opinion the pegmatitic bodies were most probably formed by local anatexis of the immediately adjacent host rocks as a result of deformation connected to thrust tectonics late in the Sveconorwegian orogeny.

The two biotite/whole-rock ages of 392 m.y. and 396 m.y. for the Jostedal Complex WNW of Hæstadfjorden suggest a Caledonian influence in the area. These results are consistent with a biotite age of 408 m.y. obtained by Brueckner (1972) for the Holsen Gneiss from the north shore of Holsavatn. Other data reported from the Basal Gneiss Region (Broch 1964, McDougall & Green 1964, Brueckner et al. 1968, Strand 1969, Priem et al. 1970, Bryhni et al. 1971, Brueckner 1972, Pidgeon & Råheim 1972, Sturt et al. 1975) also confirm that an important Caledonian event took place around 400 m.y. ago.

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